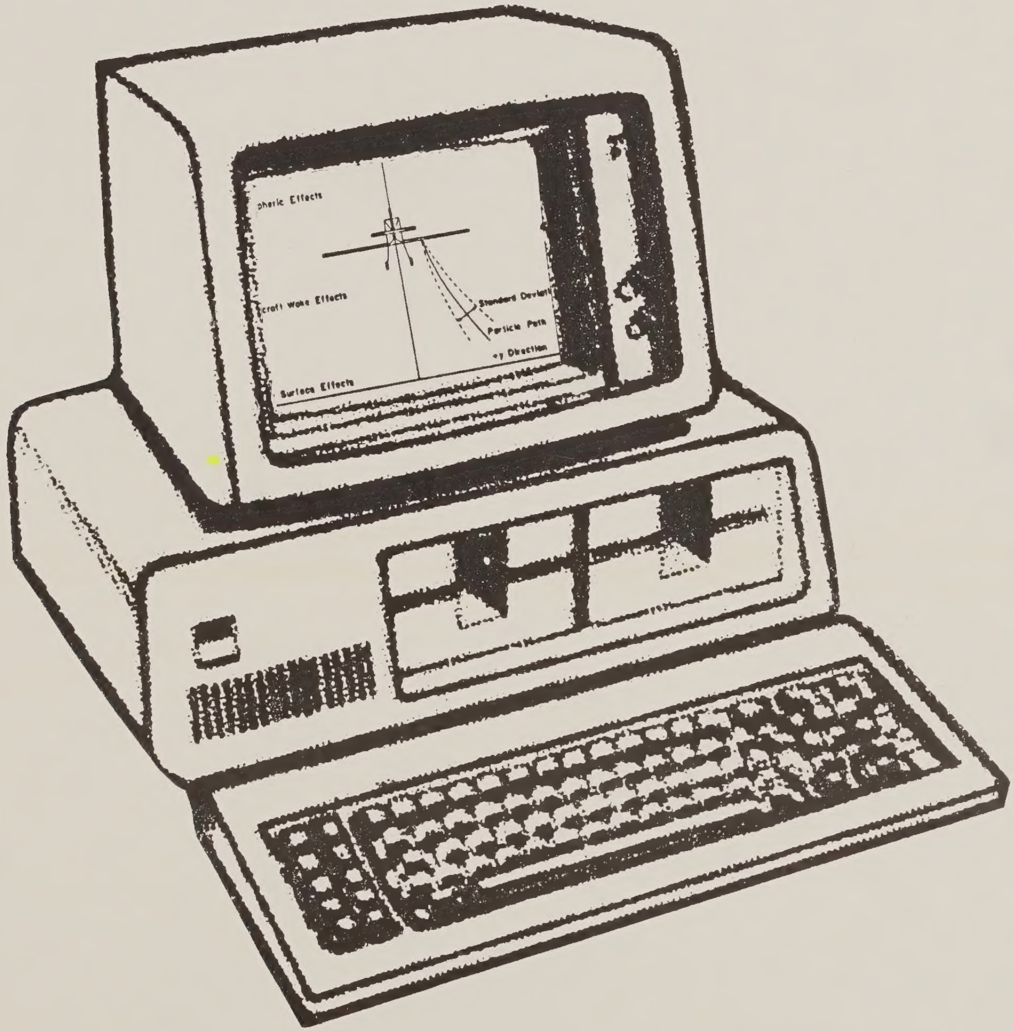
United States
Department of
Agriculture

Forest Service

**Equipment
Development
Center**

Missoula, Mont.

A Review of Progress in Technology of Aerial Application of Pesticides



3400—Forest Pest Management
8334 2803

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The mention of products and companies by name does not constitute endorsement by the USDA, nor does it imply approval of a product to the exclusion of others that may also be suitable.

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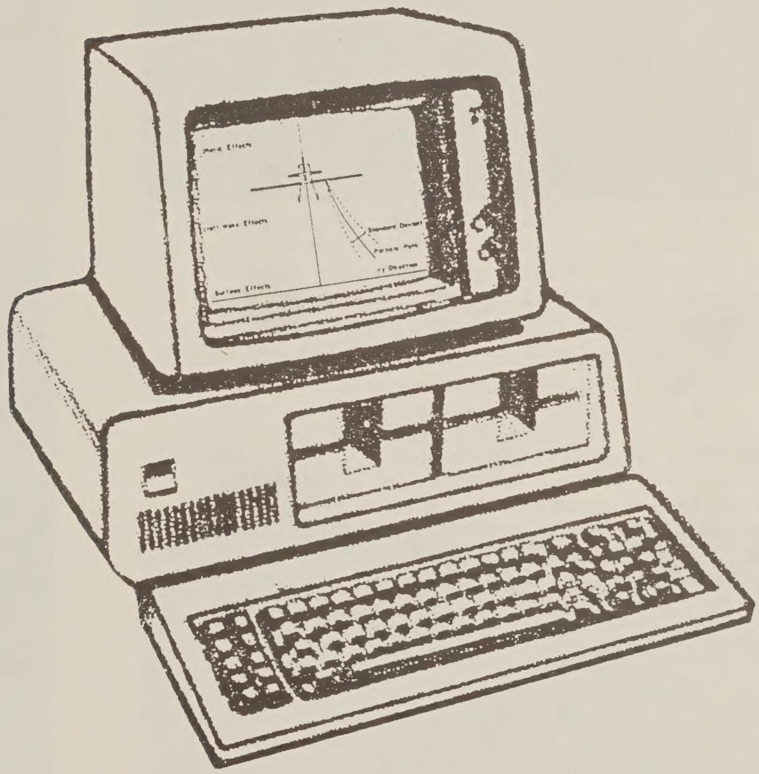

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1. INTRODUCTION

Seven years ago I spoke at the Fourth National Conference on Fire and Forest Meteorology in St. Louis on meteorology and pesticide application. During that seven-year interval the United States has successfully launched and recovered two space shuttles, one of them five times; the previously almost unheard of personal computer was selected as Time magazine's "Man of the Year"; last year an artificial heart was successfully implanted in a man.

I cannot report similar dramatic progress in aerial application of pesticides to forest and range. However, we believe that significant progress has been made in some areas. One of these areas is modeling and simulation for predicting spray behavior, improving deposition, and reducing drift. That is the topic I plan to discuss today.

2. PROBLEMS OF WILDLAND SPRAYING

I will begin with a brief review of the problems facing the aerial applicator and how we have organized the problems to solve them. The problems are illustrated in figures 1a through 1l.

Forest spraying presents many problems not found in normal agricultural spraying:

a. Because of the concentrating effect of mountain valleys and canyons, significant concentrations of insecticides can be carried several miles.

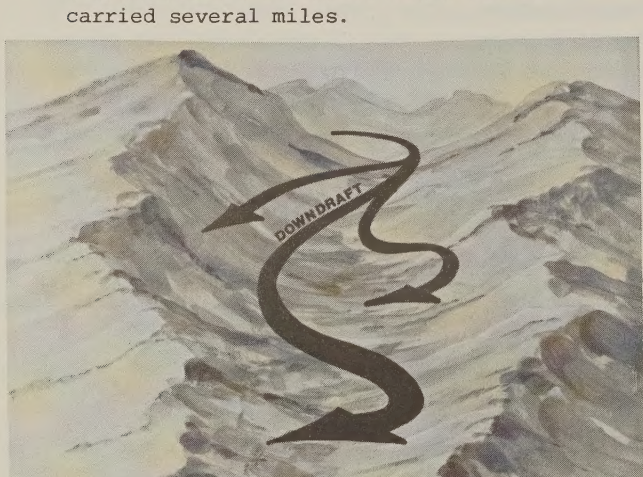

Figure 1a.

b. Instead of falling a few feet as in the case of cotton spraying, forest insecticides must travel 50 to 150 feet vertically to reach a target. Losses, due to evaporation, become more significant both in terms of greater drift and loss of insecticide.

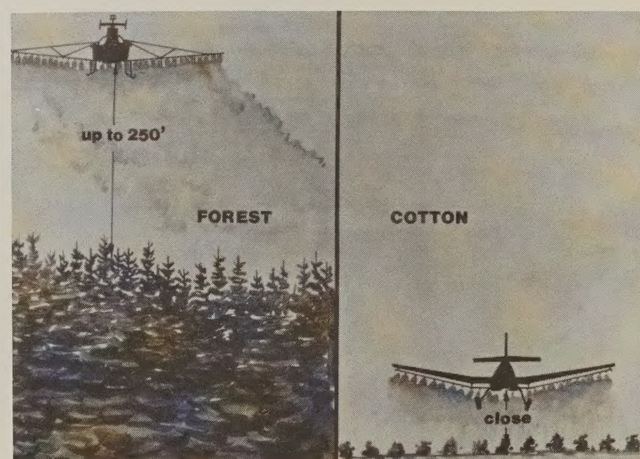

Figure 1b.

c. The dense forest foliage may capture all of the insecticide within a few feet resulting in only one side of the tree being sprayed.

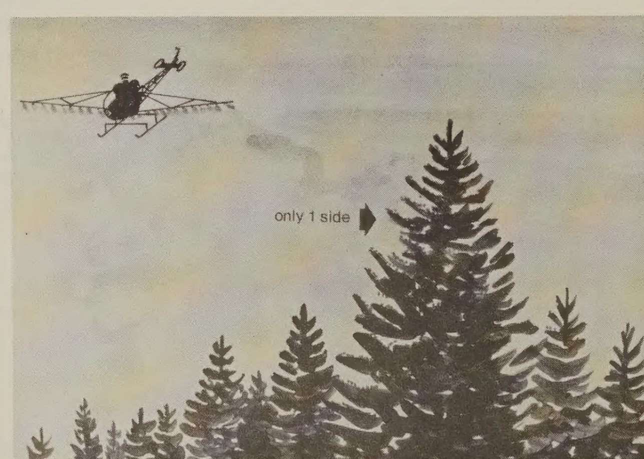

Figure 1c.

d. On the other hand, the drops may be so small that they are deflected around the target by aerodynamic forces.

Figure 1d.

e. If the lateral displacement of the spray is excessive the applicator cannot predict where it will reach the forest and has lost effective control of the spray.

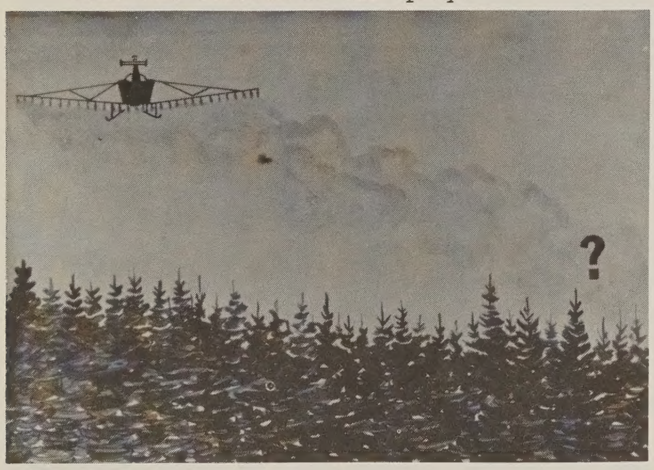

Figure 1e.

f. In his zeal to prevent excessive lateral displacement, the applicator may select drops so large, that too few numbers of drops are available for effective coverage.

Figure 1f.

g. It is difficult to fly evenly spaced swaths over large, irregular tracts of forest having few roads or identifying boundaries.

Figure 1g.

h. Steep slopes present several problems. The actual surface area is greater than shown on a map; the downhill side of the boom may be 30 feet higher above the trees than the uphill side of the boom. Flight path and direction are limited to terrain contours because the aircraft cannot climb steep slopes.

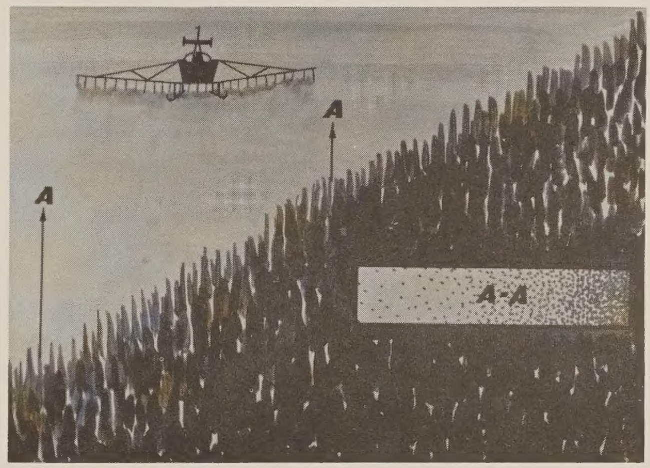

Figure 1h.

i. Rough irregular terrain is usually associated with steep slopes. If the applicator flies a level path his altitude above the terrain varies continuously; if instead he follows the terrain, roller coaster fashion, his speed and application rate vary continuously.

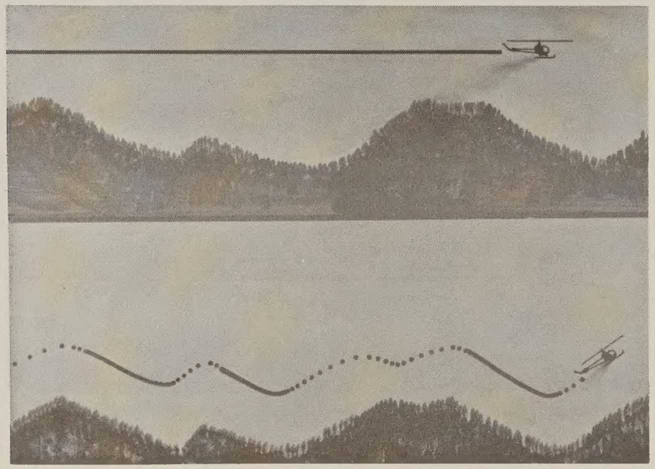

Figure 1i.

j. In an effort to obtain better coverage, the applicator may increase the volume of insecticide carried without giving adequate consideration to the lethal drop size, requiring hundreds of drops to kill a larva rather than one drop.

Figure 1j.

k. The aircraft wake has a major influence on the spray behavior. Small drops are entrained in this spray cloud and transported in a manner similar to smoke ring movement. Other larger drops fall independently of the vortex but are not readily visible. Thus, the applicator may be misled by observing the visible cloud.

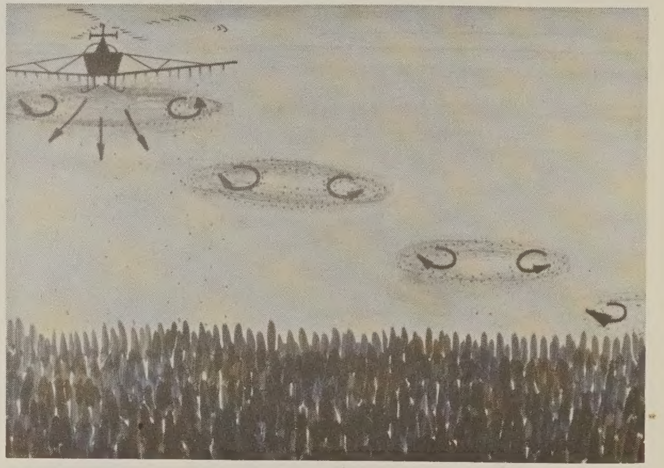

Figure 1k.

l. In two hours of morning spraying, weather conditions usually vary from an inversion to neutral or unstable. The applicator may not be aware of these changes.

Figure 1l.

3. AN APPROACH TO ORGANIZING THESE PROBLEMS

This is a formidable array of problems, and it is a tribute to aerial applicators that they carry on successful spray projects despite these problems and lack of knowledge in some of the areas.

We have devised the following scheme to allow us to define each part of the problem separately and yet consider all of the parts simultaneously.

Figure 2 shows the effect of a droplet being carried so far away that it is essentially beyond the control of the applicator. Here we have a plot of droplet diameters versus wind speed above the canopy. The shaded area to the left is the area in which the drops would be carried too far. We have somewhat arbitrarily chosen 1,000 feet as too far. In some circumstances it would be more and in some less. We see that there is an area on the right within which the drops can be contained and an area to the left that we want to avoid.

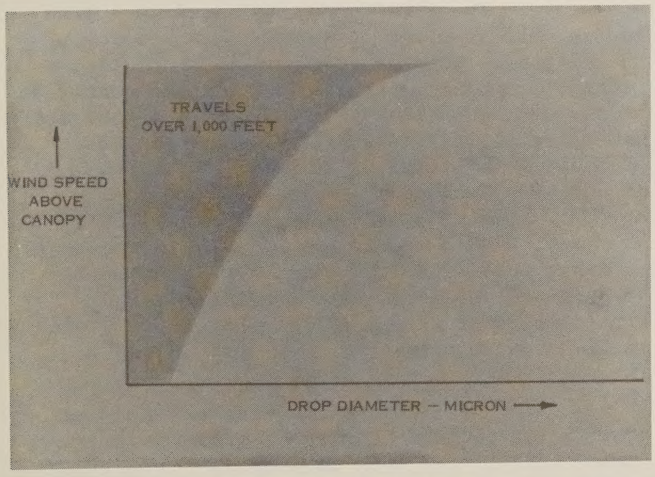

Figure 2.--Excessive swath displacement.

Figure 3 shows another aspect of the problem. This is a representation of the fact that large droplets will not penetrate the canopy. That is they will be filtered out by the first foliage encountered and cannot be uniformly deposited throughout the canopy. In this case the permissible area is on the left. The avoided area is on the right.

In figure 4 we have the same coordinates, but we demonstrate the area in which sufficient drops are not available to provide adequate coverage. This is based, of course, on some reasonable amount of total volume of material being delivered.

Figure 5 shows the relationship between wind speed and drop size for one value of turbulence.

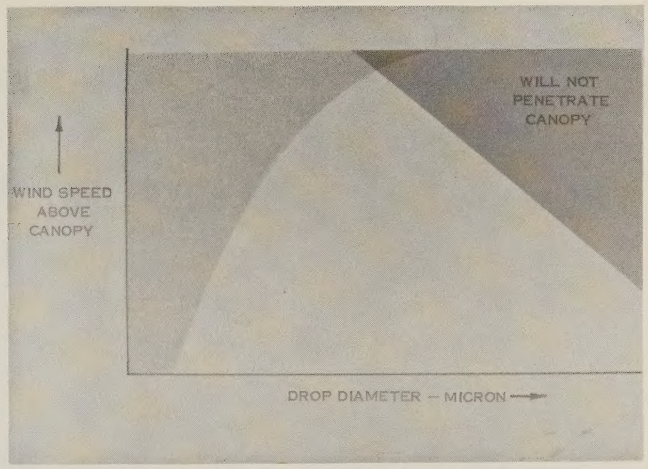

Figure 3.--Drops too large to penetrate canopy.

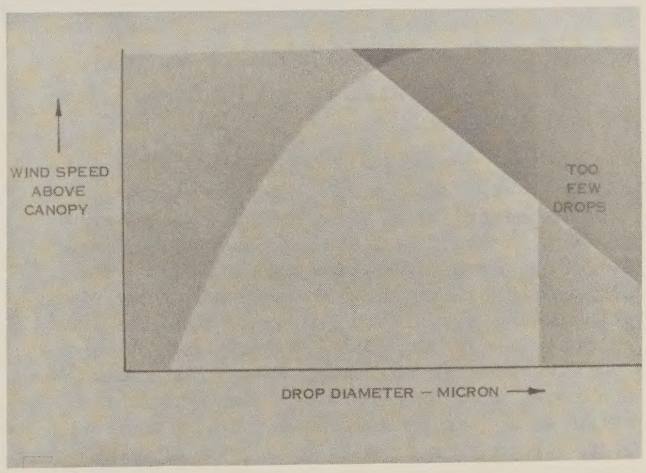

Figure 4.--Too few drops per coverage.

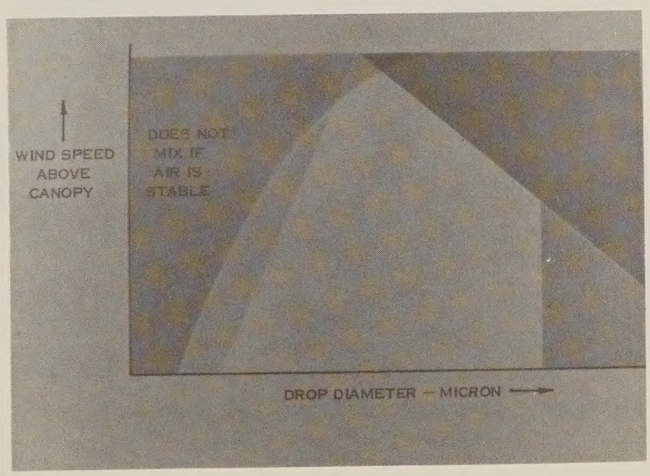

Figure 5.--Lack of turbulence affects deposition.

Figure 6 shows the area where, because the wind speed is too low and the drops are too small, they will not impinge on the target. In this case the target could be either foliage or insect.

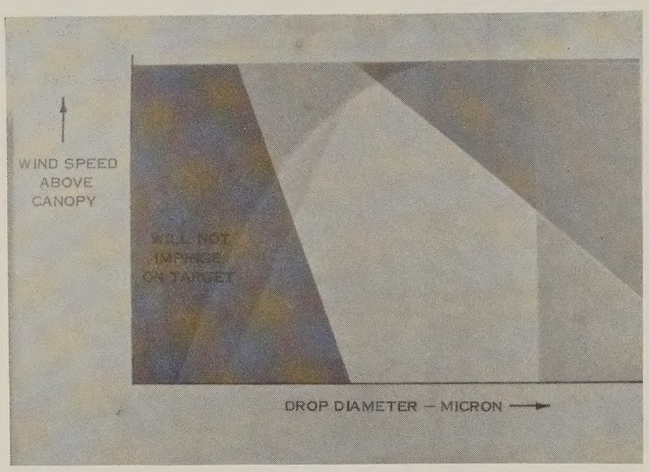

Figure 6.--Drops are deflected around target.

In figure 7 we show all of the curves on the same graph. In the center is an area of useful drop sizes bounded by several areas that are not useful. The range of useful drops can be divided into two classes. The drops on the left side are so small they are principally airborne. Their terminal falling velocity is so low that they are carried wherever the wind and aircraft wake take them. On the right side are the large drops that are affected by air movements, but their arrival at the target is primarily through gravitational settling.

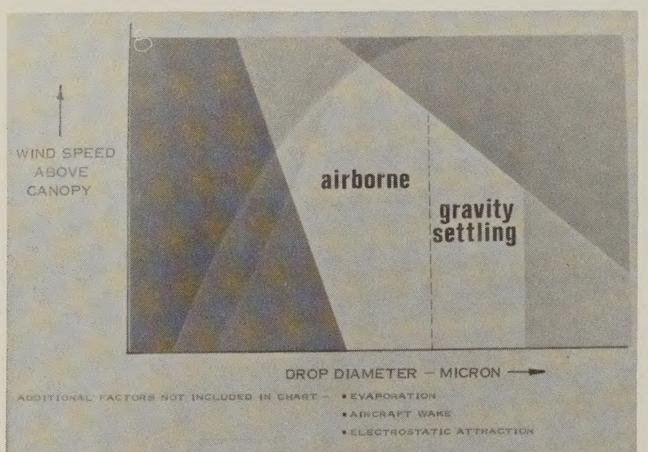

Figure 7.--Envelope of optimum drop size.

This last figure demonstrates an approach to the entire problem of predicting spray behavior where a multitude of factors are involved and must be considered simultaneously. Other factors, such as evaporation, also can be shown by adding another axis or dimension to the graph.

What is also demonstrated is the complicating fact that the physical behavior of the drops in the optimum range are governed by two different sets of equations; one for the airborne particles; another for the large particles subject primarily to gravitational settling. This has led to the development of two simulation models: AGDISP and FSCBG.

The AGDISP model is based on actually tracking the motion of discrete particles. The dynamic equations governing the particle trajectory are developed and integrated. The equations include the influence of the aircraft dispersal system configuration, aircraft wake turbulence, atmospheric turbulence, gravity, and evaporation.

The FSCBG model is based on a line source that is given an initial disturbance by the aircraft. The line source develops into a spray cloud that is treated as a tilted Gaussian plume. The equations track the mean position of the plume as well as rate of change of its horizontal and vertical variance. Evaporation effects are included.

Both models can be used independently to track spray from the time of release until deposition. However, each model has a range within which it provides the best accuracy and is the most computationally efficient.

To link the two models for a complete picture of potential spray behavior, a coupling code, AGLINE, has been developed. The AGDISP model is run until the released material becomes a spray cloud. Then the FSCBG model uses the AGDISP predictions to create a Gaussian plume model. This gives a complete predictive code, accurate from the time of release until long after the released material can be treated as a cloud. All important forces influencing the evolution of the released material are accounted for and the increase in computer time is nominal.

Again, the two simulation models, AGDISP and FSCBG, can be used independently or jointly with the coupling code, AGLINE.

The principal outputs are deposition and drift, but the models can be programmed to give intermediate information on drop velocity, evaporation, flow fields, and other factors.

Inputs to the models describe the aircraft, nozzle, evaporation rate, meteorology, and biological environment. Obtaining sufficiently accurate model inputs is as difficult and challenging as development of the models themselves. The inputs are estimated, measured, calculated, or selected.

The relationship of the models' inputs and outputs are shown in figure 8. Major inputs concerning aircraft are fixed wing or helicopter, speed, wing span, weight, wing loading, propeller characteristics, and wake characteristics (fig. 9).

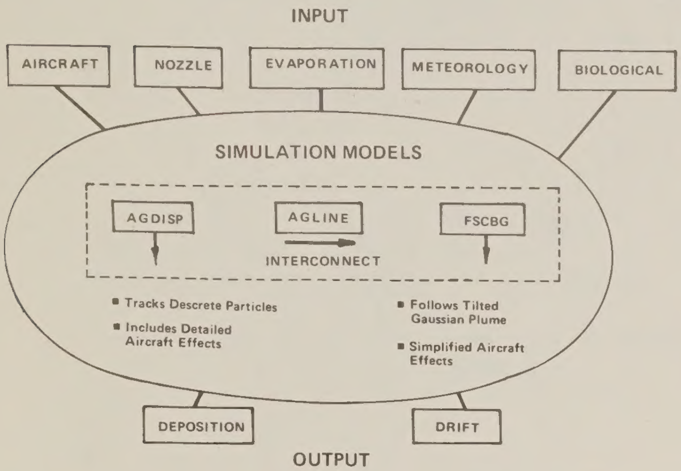

Figure 8.--Model relationship.

AIRCRAFT	**Helicopter, Biplane, Monoplane** **Speed** **Wing Span** **Weight** **Wing Loading** **Propeller Characteristics** **Wake Characteristics**

Figure 9.--Aircraft inputs.

The major inputs for the spray system (fig. 10) are nozzle, droplet distribution, number of nozzles, location of nozzles, and flow rate. Obtaining an accurate description of the droplet distribution at the aircraft has been difficult. Along with the other groups, the USDA Forest Service sponsored the development of a wind tunnel and laser measuring device at the University of California, Davis, Agricultural Engineering Department (fig. 11). We can now routinely measure droplet size distribution at aircraft speeds, as shown in figure 12.

SPRAY SYSTEM	**Nozzle** **Droplet Distribution** **Number of Nozzles** **Location of Nozzles** **Flow Rate**

Figure 10.--Spray system.

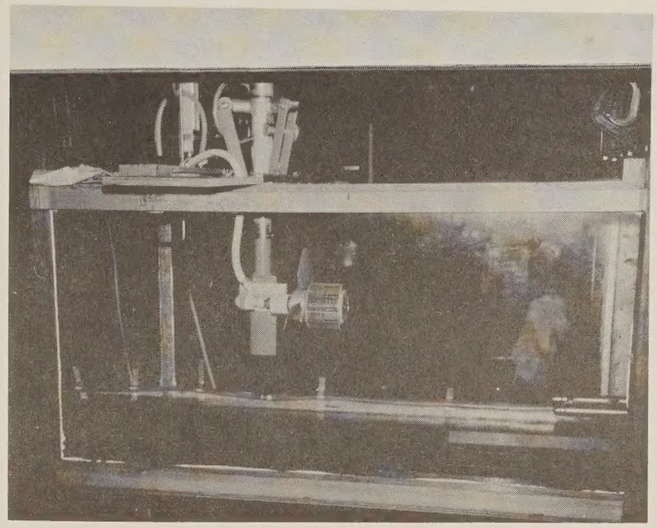

Figure 11.--Wind tunnel with nozzle and drop-sizing device.

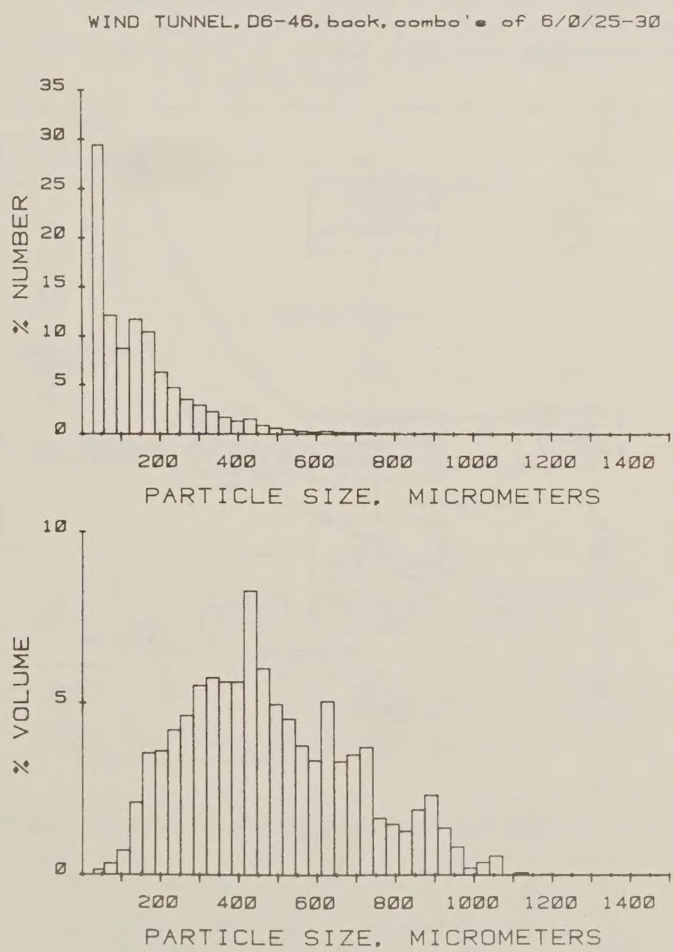

Figure 12.--Typical drop size distribution.

The major evaporation inputs are temperature, relative humidity, velocity, and evaporation rate (fig. 13). The evaporation rate is estimated from mathematical models; for complex mixtures, solutions, or suspensions, it is measured. The Forest Service sponsored a project at Colorado State University's Aerosol Sciences Laboratory to develop a laboratory method to measure droplet evaporation rate.

EVAPORATION Temperature
Relative Humidity
Evaporation Rate
Velocity

Figure 13.--Evaporation inputs.

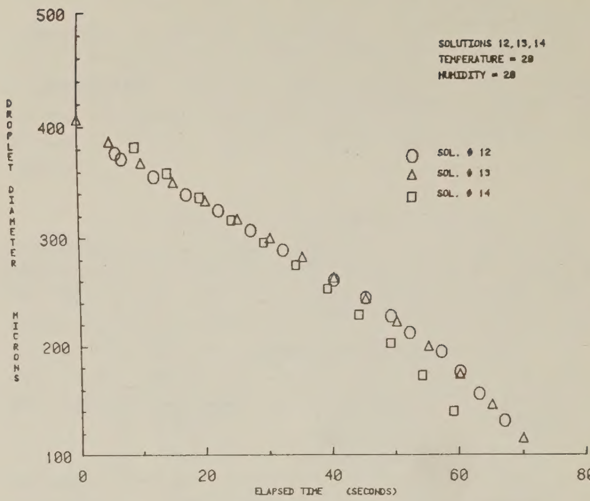

Figure 15.--Measured evaporation rate of water drops.

Figure 14 is a schematic of the entire system. It is controlled by a microprocessor and measures evaporation rate at controlled temperature and humidity while maintaining flow past the droplet at terminal velocity corresponding to its changing diameter. This shows an example of results for three different mixtures (fig. 15).

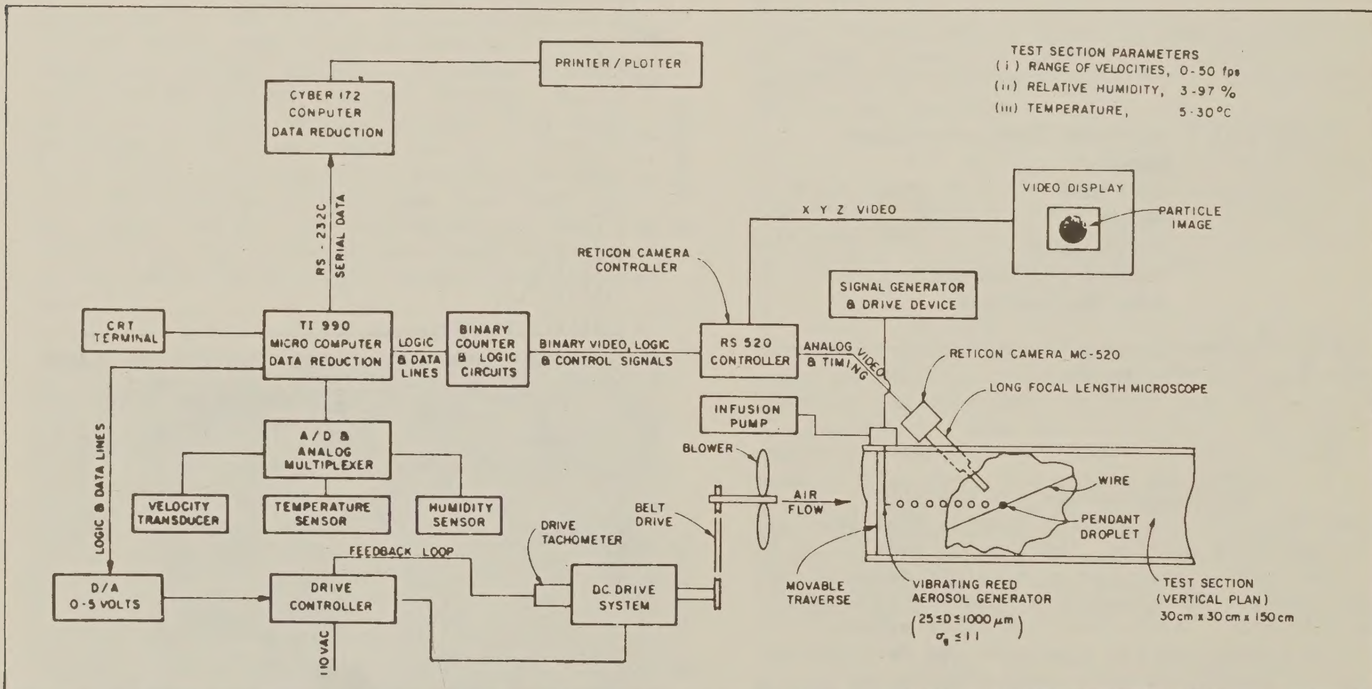

Figure 14.--Schematic of wind tunnel to measure evaporation rate.

The AGDISP and FSCBG models accept the following meteorological data: vertical wind speed and direction, temperature profile, relative wind speed, turbulence, depth of mixing layer, vertical profile of wind speed, vertical profile of wind direction, effect of canopy, and effect of complex terrain (fig. 16).

METEOROLOGY Vertical Speed and Direction
Temperature Profile
Relative Wind Speed
Turbulence
Depth of Mixing Layer
Vertical Profile of Wind Speed
Vertical Profile of Wind Direction
Effect of Canopy
Effect of Complex Terrain

Figure 16.--Meteorology inputs.

Information on the biological environment needed for the models includes details of the forest type, terrain classification, and pesticide toxicity (fig. 17).

BIOLOGICAL	Forest Classification Terrain Classification Pesticide Toxicity

Figure 17.--Biological inputs.

The FSCBG model is the older of the two models and has been described in detail in various publications. The AGDISP model is in the final stages of development and verification and will be available this fall.

My last four figures show the graphic output of the AGDISP model. The top of figure 18 shows the trajectory of 300-micrometer droplets released from 13 nozzle locations of a Thrush 600 airplane flying 105 mph at 50 feet above the terrain. The ground deposition of spray across the aircraft flight path is shown at the lower part.

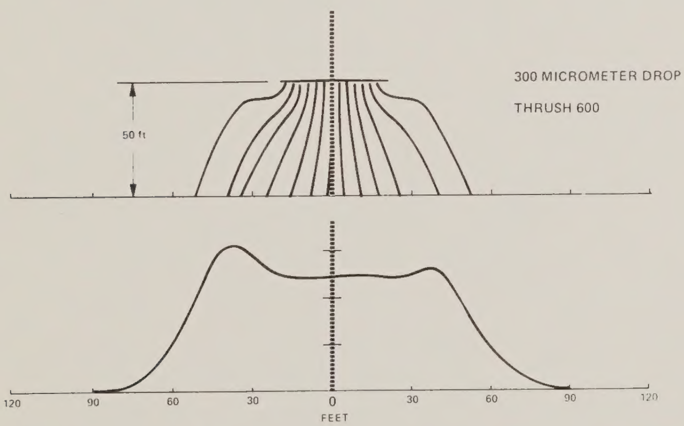

Figure 18.--Drop trajectory and deposition pattern.

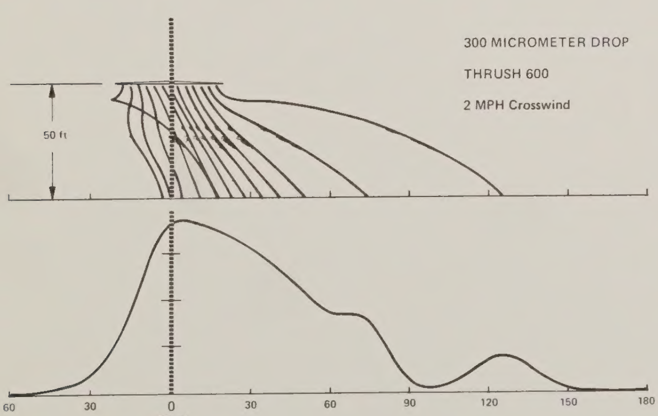

Figure 19.--Drop trajectory and deposition pattern with crosswind.

Figure 19 shows the same configuration with a 2-mph crosswind. Figure 20 shows the same configuration without a crosswind but with 150-micrometer droplets, half the diameter of the droplets in figure 18. This shows the droplet entrainment in the wing tip vortices that aggravates the problem of drift. Figure 21 shows the droplet's vertical velocity, an example of other information that is available from the model.

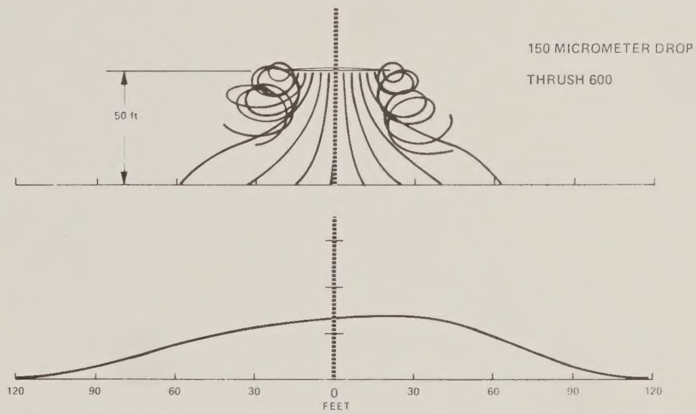

Figure 20.--Trajectory and deposition pattern of small drops.

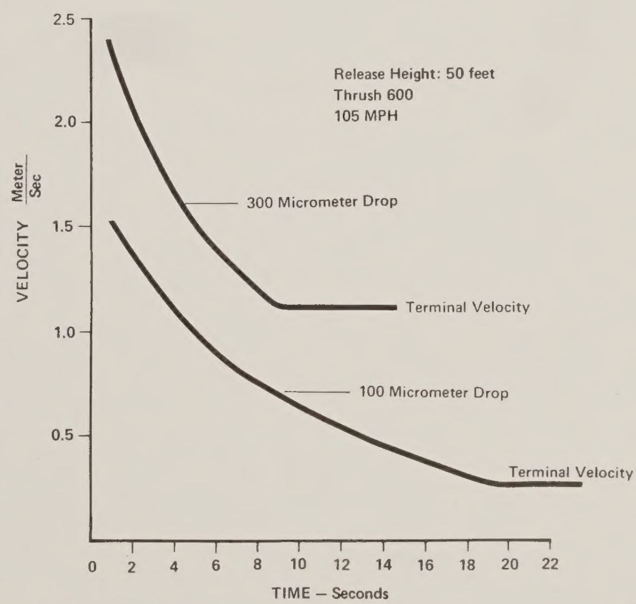

Figure 21.--Change in vertical velocity with time.

We believe the major shortcoming of these models is inadequate meteorological input. In particular we need better descriptions of flow within the canopy and vertical flow profiles generated by drainage flow rather than mesoscale winds. We also need a fully operational three dimensional, complex terrain winds model.

In summary, we now have models that account for all important forces influencing the dispersion and deposit of aerial sprays. We have estimates of inputs to make the models useful to forest managers. Further improvement in model results, particularly drift estimation, depends on better meteorological input.

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